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Special Edition

Flood analysis in the Canoas, sertão, and Mampituba rivers in the South of Brazil through hydrological and hydrodynamic modeling

Análise de inundações nos rios Canoas, Sertão e Mampituba, Sul do Brasil por meio de modelagem hidrológica e hidrodinâmica

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ABSTRACT

Floods that occur in hydrographic basins with high slopes are more susceptible to natural hazards due to the occurrence of high intensity hydrological events and the type of sloping relief. These two associated factors contribute to an increase in the destructive potential of these regions, causing economic damage and loss of life for people and animals. This study sought to assess the floodplain areas in the Canoas, Sertão, and Mampituba Rivers that contribute to the Mampituba River basin in southern Brazil, to support emergency procedures for dealing with floods and contribute to the territorial management of these spaces. From the hydrological data of the Mampituba River basin, a hydrological model was used, which generated flows that were inserted as input to a hydrodynamic model, resulting in flood patches in the plains of the modeled rivers. The calibration and integration studies of the models were carried out on a computational platform that employs the hydrometeorological knowledge represented by the models of the basin under study. The hydrodynamic modeling represented in the maps indicated that the flooding patches occur within the river channels and in the plains occupied by agriculture, with a predominance of irrigated rice paddies, pasture fields, forestry, urbanized areas, and native vegetation. In the urban region along the floodplains of the Praia Grande and Mampituba Cities, there are inns, restaurants, and residences which can suffer structural damage and expose people to the danger of a flood event of this magnitude. The results achieved allow us to infer that the integrated modeling system proved to be capable of performing efficient hydrological and hydrodynamic simulations. The methods used can be replicated in other basins and the results can support public managers for greater assertiveness in decision-making when facing the dangers of extreme weather events.

Keywords: Water resources; Extreme hydrological events; Hydrological and hydrodynamic modeling

RESUMO

As inundações que ocorrem em bacias hidrográficas com declividades elevadas são mais susceptíveis a perigos naturais, devido à ocorrência de eventos hidrológicos de alta intensidade e ao tipo de relevo declivoso. Esses dois fatores associados contribuem para um aumento do potencial destrutivo desses locais, trazendo prejuízo econômico e perda de vida de pessoas e animais. Esse estudo buscou avaliar as áreas de planície de inundação nos rios Canoas, Sertão e Mampituba contribuintes da bacia do rio Mampituba, Sul do Brasil, com intuito de apoiar os procedimentos emergenciais de enfrentamentos de inundações, e contribuir com a gestão territorial destes espaços. A partir dos dados hidrológicos da bacia do rio Mampituba, foi utilizado um modelo hidrológico, o qual gerou vazões que foram inseridas como entrada para um modelo hidrodinâmico, resultando em manchas de inundação nas planícies dos rios modelados. Os estudos de calibração e integração dos modelos foram realizados numa plataforma computacional que emprega o conhecimento hidrometeorológico representado pelos modelos da bacia em estudo. A modelagem hidrodinâmica representada nos mapas indicou que as manchas de inundação ocorrem dentro da calha dos rios e nas planícies ocupadas por agricultura, predominando canchas de arroz irrigado, campo de pastagem, silvicultura, área urbanizada e vegetação nativa. Na região urbana junto as planícies de inundação dos municípios de Praia Grande e Mampituba, existem pousadas, restaurantes e residências, que podem sofrer danos estruturais e expor as pessoas ao perigo de um evento de inundação dessa magnitude. Os resultados alcançados, permitem inferir que o sistema de modelagem integrada se mostrou capaz de realizar simulações hidrológicas e hidrodinâmicas eficientes. Os métodos empregados podem ser replicados em outras bacias e os resultados poderão subsidiar os gestores públicos para maior assertividade na tomada de decisão ao enfrentamento dos perigos dos eventos climáticos extremos.

Palavras-chave: Recursos hídricos; Eventos hidrológicos extremos; Modelagem hidrológica e hidrodinâmica

1 INTRODUCTION

Floods are a global phenomenon that has affected people's lives since ancient times. Among natural disasters, floods stand out for their recurrence, scope, and capacity for destruction (TENG *et al*., 2017). In extreme events of rainfall, it is natural that there is an increase in flow in water courses, often overflowing the river channel reaching the floodplain. In urbanized regions, this is exacerbated by the waterproofing of the soil and the creation of several artificial obstacles (SARTORI, 2018).

Neto *et al*. (2015) described that several cities in Brazil were being installed and expanded to the floodplain areas of rivers, resulting in the occurrence of great economic damage, both to the physical structure and in loss of human life.

Therefore, demarcating areas subject to flooding is a crucial activity for planning and managing soil use (TUCCI, 2007).

Long-term flood forecasting quantifies the chances of a flood occurring in statistical terms, but without determining the exact moment when it will happen. It is based on past level occurrence statistics and allows one to establish flood levels for selected hazards. Accordingly, it represents an important tool for public managers for environmental and territorial planning (RIBEIRO and LIMA, 2011).

Silva (2015) describes that the phenomena associated with the prediction of extreme hydrological events are characterized by the use of advanced computational tools combined with hydrological and hydrodynamic modeling procedures, which simulate the behavior of the main physical phenomena involved in flood events. Flood events must undergo hydrological and hydrodynamic studies through mathematical simulation. The combination of these models allows the assessment and delineation of the flooded area considering events that have occurred and projected for different return periods (LASTRA *et al*., 2008; KNEBL *et al*., 2005).

Many authors consider that hydrological models are one of the main tools employed for the management of water resources, as they allow the simulation of temporal variations of natural phenomena, evaluating different combinations of events (VIOLA *et al*., 2009). Among the various applications, hydrological modeling can be used to assess the impacts resulting from modifications carried out in natural environments, as a tool for designing projects and also to predict the consequences of hypothetical scenarios (MARINHO FILHO *et al*., 2013).

Hydrological models have been widely used in flood risk mapping (APEL *et al*., 2006; DUTTA *et al*., 2006), in flood damage assessment (BHUIYAN and DUTRA, 2012; MERZ *et al*., 2010), in real-time flood forecasting (ARDUINO *et al*., 2005), in flood-related engineering (GALLEGOS *et al*., 2009), and in water resources planning (VAZE *et al*., 2013). In addition, it has been used as an important prerequisite for transporting contaminants (KARIM *et al*., 2015) and in the hydrology of the river system (DUTTA *et al*., 2013).

The integration of hydrological models to the Geographic Information System (GIS) has grown significantly in recent years (CABRAL *et al*., 2016). This integration has corroborated the planning and decision making to extreme event problems, since they are tools used to predict flood flows and mapping flooded areas. According to Sartori (2018), hydrodynamic models allow mapping velocities and flow directions.

Among the hydrological models, Fan and Collischonn (2014) describe that the rainfall-runoff models aim to represent the part of the hydrological cycle that lies between the occurrence of rainfall and its transformation into flow.

Interception of rainwater by vegetation, surface water accumulation, evapotranspiration, percolation, infiltration, surface runoff, and flow of groundwater are among the hydrological phenomena that are involved and can be considered in a rainfall-runoff model. It is important to emphasize that there are other hydrological phenomena that can be considered in addition to those before-mentioned.

Originally, the hydrological models were developed from the need to obtain longer and more representative historical flow series for watercourses. As a consequence, based on information related to the precipitated depth in a given location, it is possible to estimate the unknown flows related to the hydrographic basin under study (TUCCI, 1998; FAN *et al*., 2015).

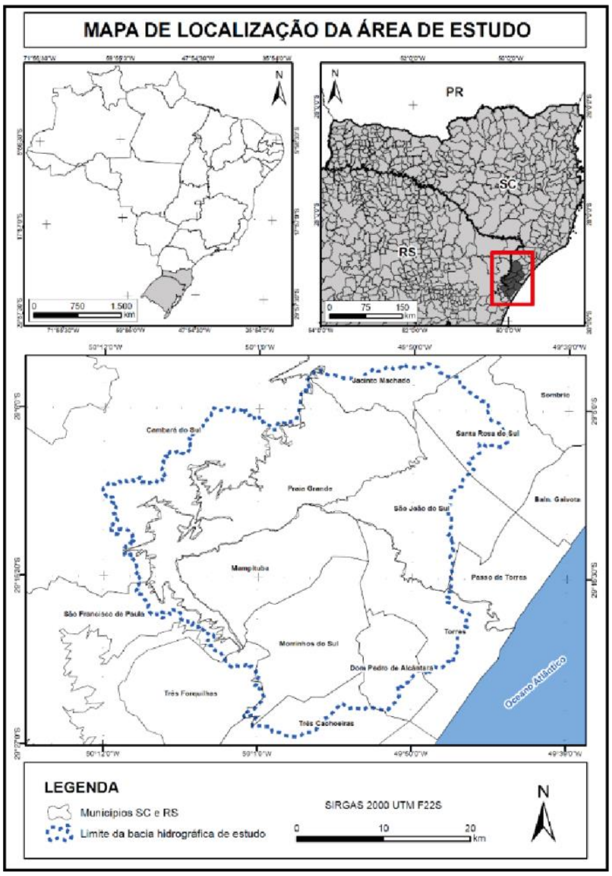
Based on these initial considerations, this study proposed to carry out a hydrological and hydrodynamic modeling in order to assess the occurrence of flood events in lowland areas of the Canoas, Sertão, and Mampituba Rivers, part of the Mampituba River basin, located in the south of Brazil. This region is very susceptible to flood events and, therefore, the results obtained using the models can be used to support emergency procedures and contribute to the territorial management of these spaces.

1.1 Study area

The Mampituba River hydrographic basin (MRHB) is a transboundary basin, covering parts of the territory of the extreme northeast of Rio Grande do Sul State (722.73 km²) and occupying part of the territory of the extreme southeast of Santa Catarina State (1,219.31 km²) with a total drainage area of 1,942.04 km².

Its main springs are in the plateaus of the Aparados da Serra National Park and Serra Geral National Park in Cambará do Sul City. This region has the highest altitudes in the basin, reaching 1,134 meters above sea level. The rivers that form in this region descend through the canyons in regions with steep slopes forming several waterfalls until they meet at an altitude of 799 m, where they form the Mampituba River, which is the dividing line between the states of Rio Grande do Sul and Santa Catarina.

Figure 1 – Location of the study watershed area



Source: Authors, 2021

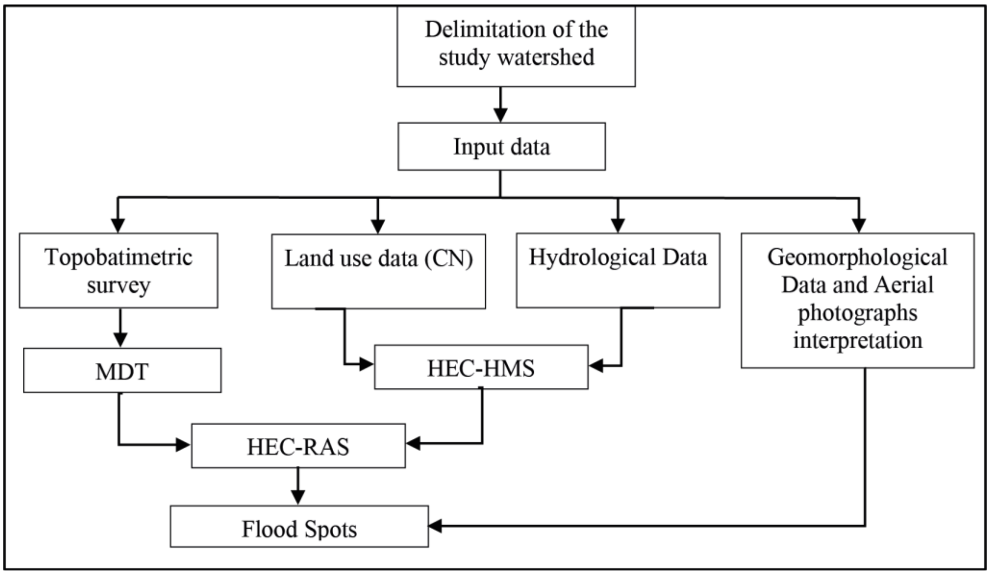
At this location, the river divides the Praia Grande City in Santa Catarina State and the Mampituba City in Rio Grande do Sul State, to the point where the river forks in two directions, one to the northeast, and the other to the southeast. The pluvial regime in the basin region of this study is influenced by the relief with an accentuated occurrence of orographic rains. Back and Poleto (2018) highlight that orographic rain events are related to floods and landslides on the coast of the southern and southeastern regions of Brazil.

For the hydrological and hydrodynamic simulations, a study area inserted in the hydrographic basin of the Mampituba River was delimited. This study area (Figure 1) is 1,211.97 km², with a perimeter of 201.66 km, and a watercourse extension of 83.78 km. It starts at the source of the Mampituba River until the place where the Sertão River joins the Mampituba River.

2 MATERIAL AND METHODS

The main work steps required for the development of flood simulations are described in Figure 2.

Figure 2 – Flowchart of the methodological procedures



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2.1 Topobatimetric survey

39 points of bathymetric sections of rivers were surveyed using the methodology suggested by NBR 13.133/1994. This establishes the conditions required for the execution of a Topographic Survey, together with the document of Specifications and Norms for Geodetic Surveys Associated with the Brazilian Geodetic System.

This document establishes the minimum requirements for geometrical positional accuracy, thus making on-site data collections georeferenced to a coordinate system. The survey of the sections was also aided with the Real Time Kinematic (RTK) method (INCRA, 2013) and supported with Total Station. Global Navigation Satellite System (GNSS) receiver with External Radio link was also used.

With this procedure, it was possible to carry out the Real Time Kinematic (RTK) survey. The horizontal profiles of the bathymetric sections of the studied rivers were prepared with a vertical scale of 1:500 and a horizontal scale of 1:1000. The survey of bathymetric sections served as input data to the hydrodynamic model.

2.2 Geomorphology and aerial photographs interpretation

The geomorphology and aerial photographs interpretation studies were carried out to support the hydrodynamic modeling studies seeking to understand the modeled flood areas. The geomorphology was described with a field survey and through information available in the Management Plan of the Aparados da Serra and Serra Geral National Park (BRASIL, 2003).

The aerial photographs interpretation was made through time clippings that total a time lapse of more than six decades, starting with the aerial survey dated 1957 and ending with the orbital imaging dated January 2020. The goal was to comprehend the variation and the behavior of river channels and anthropic interventions that have occurred in the last 60 years and to corroborate the definition of flood spots.

To assess the drainage network, multitemporal analysis activities used, based on the interpretation of aerial photos and orbital images (intervals from 1957 to 1978), from the Santa Catarina State Government Planning Secretariat; 2000 from the Brazilian Institute of Geography and Statistics - IBGE; 2010 of the Aerophotogrammetric Survey of the Santa Catarina State from the Department of Sustainable Development of the Santa Catarina State. Moreover, the clippings for 2013 and 2020 were taken from Google Earth® software.

2.3 Input data

As input data necessary for the development of this study, the historical series of hydrometeorological variables (precipitation, flow, and evapotranspiration), data referring to the type and use of the soil, and information related to the terrain altimetry are included.

Regarding the historical series of meteorological variables, these were obtained from pluviometric and fluviometric stations that are under the responsibility of the National Water Agency and the Agricultural Research and Rural Extension Company of Santa Catarina State (Epagri). The stations used were:

1. Praia Grande pluviometric station (code 02949001), of the National Hydrometeorological Network (RHN) coordinated by the National Water and Basic Sanitation Agency (ANA), operated by the Agricultural Research and Rural Extension Company of Santa Catarina (EPAGRI). The station is located at latitude 29°11'41'' S and longitude 49°57'48'' W, at an altitude of 60 meters. The historical series is from 1977 to 2019.
2. Praia Grande fluviometric station (code 84970000), under the responsibility of ANA and operated by EPAGRI. The station is located at latitude 29°11'41'' S and longitude 49°57'48'' W. The historical series is from 1986 to 2014.
3. Poço Negro fluviometric station (code 84980000), under the responsibility of ANA and operated by the Mineral Resources Research Company (CPRM). The station

is located at latitude 29°11'41'' S and longitude 49°57'48'' W. The historical series is from 2006 to 2019.

The potential evapotranspiration was determined from data from Praia Grande City, through the HidroClimaSC software (BACK, 2020).

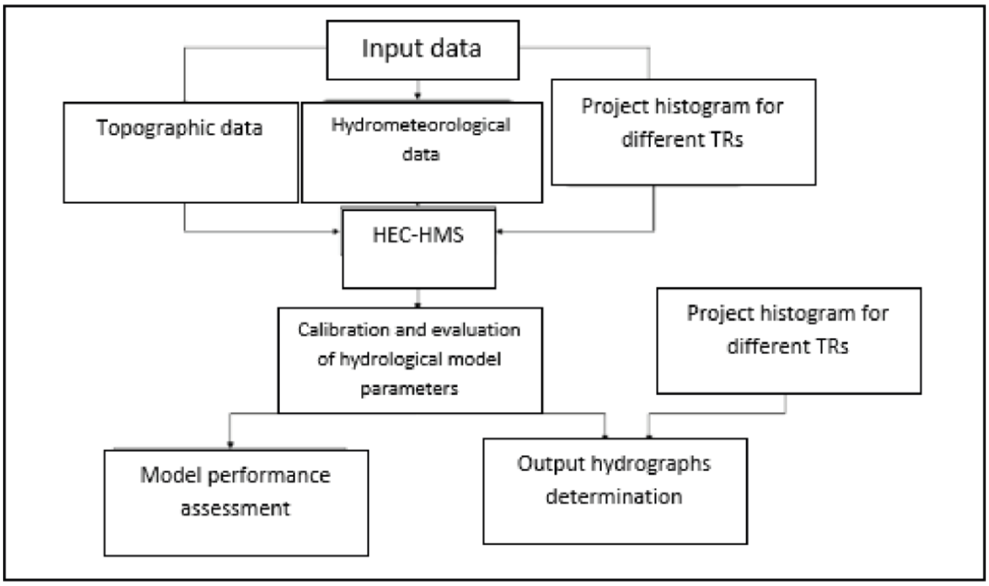
In order to determine the type and use of soil in the Mampituba River basin, information from the Water Resources Plan for the Mampituba River basin - Phase A Diagnosis (SEMA-RS, 2020) was used. Finally, the data related to the terrain altimetry refer to a Digital Elevation Model which was elaborated with data from the SRTM (Shuttle Radar Topoghaphy Mission) and has a spatial resolution of 90 meters (WEBER *et al*., 2004). The MDE used is available on the website of the Geoprocessing Laboratory (LABGEO) of UFRGS.

2.4 Hydrological modeling

After obtaining and organizing the input data, it was possible to move on to the hydrological modeling step. This was performed using the US Army Corps of Engineers HEC-HMS software (version 4.2.1) (USACE-HEC, 2016a).

Figure 3 shows the sequence used for the elaboration and calibration of the hydrological model.

Figure 3 – Flowchart of the steps of elaboration and calibration of the hydrological model



Source: Authors, 2021

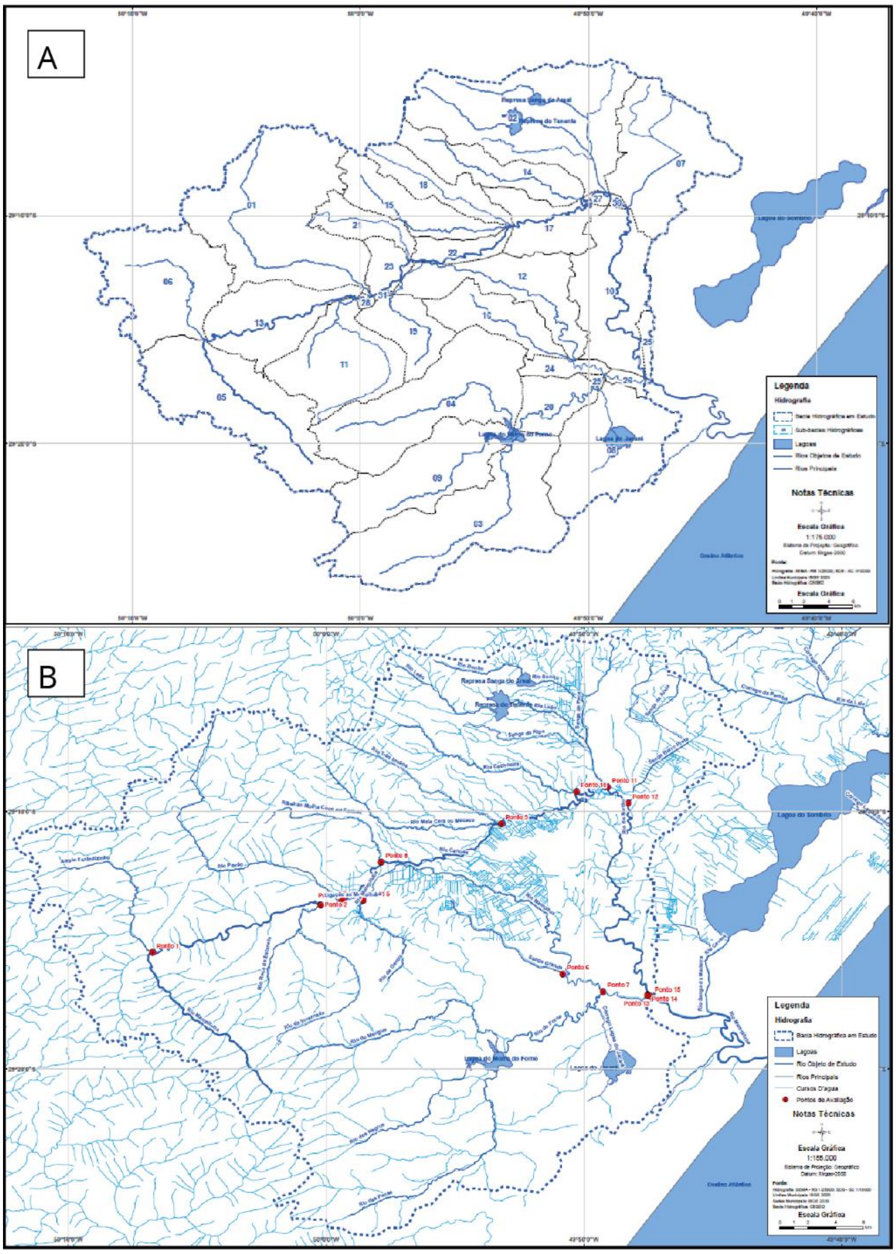
To define the histograms to simulate the response of the study area to a 24-hour rainfall and different return periods, the IDF equation (Equation 1) with precipitation data from the Praia Grande station was used. The 24-hour rainfall events were evaluated with return periods of 2, 5, 10, 15, 20, 25, 50, and 100 years.

For the temporal distribution of rainfall intensity, the third quartile of the Huff method was used, considering the curve with 50% frequency (HUFF, 1990), in order to divide the total rainfall in 24 hours into 1 hour intervals. This method has already been used by Szymanski (2020) to perform flood analysis in the sub-basins of the Molha Coco and Malacara Rivers, tributaries of the Mampituba River basin. The intense rainfall equation has a model:

$$i = \frac{KT^m}{(t+b)^n} \quad (1)$$

Where: i is the maximum average rainfall intensity (mm/h), T is the return period (years), t is the duration of rainfall (minutes) K, m, b, and n are parameters of the equation determined for each location.

Figure 4 – Division into sub-basins (A) and distribution of 15 points for hydrological assessment in HEC-HMS



Source: Authors, 2021

In the HEC-HMS, the modeling can be performed in a semi-distributed way by dividing the basin into smaller parts to represent the variation of the terrain characteristics. Thus, for the case under study, 31 sub-basins were defined, which were separated taking into account the characteristics of soil use and occupation and according to the main watercourses of the Mampituba River basin (Figure 4A). Within these sub-basins, 15 points were chosen to be evaluated by hydrological modeling (Figure 4B) which are distributed along the Mampituba, Canoas, and Sertão Rivers.

Point 1 was defined when the source of the Mampituba River joined the Arroio Faxinalzinho. Points 2 and 3 represent the Roça da Instância and Pavão Rivers flowing into the Mampituba River. At point 4, the Mampituba River is divided into two streams: the Canoas River (larger stream) and the Mampituba River (smaller stream). Points 5, 6, 7, and 14 refer to the Mampituba River (smaller stream), while points 8, 9, 10, 11, 12, and 13 to the Canoas River. After the drainage of the Sanga do Barro Preto River, the Canoas is called the Sertão River. Point 15 is the outflow of the study basin and corresponds to the downstream meeting of the Sertão and Mampituba Rivers. The method for estimating the volume of water generated during a precipitation event was the SCS-CN, from the Natural Resources Conservation Center in the United States. Its value varies between 0 and 100, where the closer the coefficient is to 100, the greater the runoff and the lesser the infiltration. Regarding the value relative to the initial losses, the HEC-HMS considers that it is equivalent to 20% of the maximum accumulated potential infiltration (USACE-HEC, 2016a), calculated according to Equation (2).

$$I_a = 0{,}2 * S \quad (2)$$

Where: Ia is the initial losses (mm) and S is the maximum accumulated potential infiltration (Equation 3).

$$S = \frac{25400}{CN} - 254 \quad (3)$$

Where: CN is the parameter value related to the infiltration capacity of the ground

The method chosen to represent the transformation of rainfall into flow was the unitary hydrograph of SCS. In HEC-HMS, the only input to the use of this model is known as the lag time. This data is equivalent to 60% of the concentration time of the basin plus half of the unitary rainy duration time (USACE-HEC, 2016a). To calculate the concentration time, the Kirpich equation was employed (Equation 4).

This equation relates the length of the main river with the difference in altitude of the basin, being developed for rural basins with areas smaller than 0.5 km² (COLLISCHONN and DORNELLES., 2013). However, Silveira (2005) showed that this equation revealed good results when applied to basins of up to 12,000.00 km².

$$Tc = 57\left(\frac{L^3}{\Delta h}\right)^{0{,}385} \tag{4}$$

Where: T_c is the concentration time (minutes), L the length of the main stream (km), and Δh the difference in altitude along the watercourse thalweg (m)

To determine the length of the river stretches, shapefiles referring to the Santa Catarina State drainage stretches in the Portal SIGSC were used. The information was processed in the ArcMap 10.3 software. The value of Δh was performed in the ArcMap 10.3 based on the MDE. Finally, the Muskigum Cunge method (USACE-HEC, 2016a) was adopted to simulate the flow propagation in rivers. The input parameters were related to the length, slope, and width of the stretches of water. These data were obtained using the ArcGis 10.3 ® software.

Finally, the performance verification of the hydrological model was performed by comparing the generated hydrographs with the historical hydrographs that were observed at the points where the fluviometric stations of Praia Grande and Poço Negro are installed. In this case, the performance metrics used were the Nash-Sutcliffe efficiency coefficient and the bias.

2.5 Hydrodynamic Modeling

The hydrodynamic simulations were performed using HEC-RAS software (Hydrologic Engineering Center - River Analysis System) version 5.0.7, of the US Army Corps of Engineers (USACE-HEC, 2016b and 2016c). The model uses the Saint Venant' equations to simulate how flow propagation occurs in rivers and channels, providing a range of information about the characteristics of the flood wave, in addition to generating flood patches (USACE-RAS, 2016a). In the case under study, simulations were performed in 2D considering the Diffuse Wave Equation. The cell size used was 30 meters in the floodplains with a refinement to 10 meters in the drainage sections area.

The simulations used the Digital Terrain Model (DTM) from aerial photogrammetric surveys as a basis. The DTM model was carried out by the State Secretariat for Social Development of Santa Catarina State (SDS-SC), which is available for download on the SIGSC Portal (http://sigsc.sds.sc.gov.br/). This MDT has a spatial resolution of one meter and a scale of 1:10,000. A refinement in the MDT was performed from the survey of topobatimetric data in the main drainage stretches of the basin under study. Accordingly, through the use of HEC-RAS, it was possible to make predictions of the flooded areas from the simulation with event data of different magnitudes defined in the hydrological model.

The determination of the Manning coefficient for the analyzed rivers and their nearest banks (100 meters) was made from the analysis of the composition of the channels, determining a Manning value in each stretch of the Mampituba, Canoas, and Sertão rivers, based on the tabulated values found in Boiten (2008) and Batista and Lara (2002).

For the floodplain areas farther from the rivers of interest, the land use map obtained in Phase A of the Mampituba River Basin Water Resources Plan (SEMA-RS, 2020) was used as a basis. A value for this coefficient was determined for each class of soil use present in the basin under study, based on tabulated values found in Chow (1959). Finally, a ramp up period of 18 hours and the computational interval of 4 seconds used were considered. The other parameters employed the default HEC-RAS settings. After defining all the configurations, the model was run considering the return times (2, 5, 10, 15, 20, 25, 50, and 100 years).

3 RESULTS AND DISCUSSION

3.1 Geomorphology and aerial photograph interpretation

The geomorphological evolution in the study region takes us back to the beginning of the Atlantic coastline of the coast of Santa Catarina State, from the fragmentation of the Gondwana supercontinent, and the opening of the South Atlantic during the Cretaceous (JUSTUS *et al*., 1983 apud BRASIL, 2003). Therefore, the entire morphological scenario of the coast of Santa Catarina State, including the area of the study basin in the headwaters of the Mampituba River shows a post-Cretaceous history. The most relevant occurrence is the survey of the Serra Geral mountain ranges, constituted by Gondwanic volcanosedimentary rocks from Paleozoic to Mesozoic ages, respectively. These features represent plateau edge scarps and this uplifting took place, probably, starting at the end of the Cretaceous and throughout the Tertiary, producing unevenness greater than 1,000m today (BRASIL, 2003).

The portion of the upper Mampituba River shows a relief dominated by hills of convex-concave geometry; a little higher hills of convex geometry; and basaltic tables. The coastal plains that occupy the outer portion of the coastal lowlands, such as the plain areas of the Praia Grande, Mampituba, Morrinhos do Sul, and São João do Sul Cities, exhibit a complex geological history marked by transgressive-regressive events that occurred along the Superior Quaternary.

In the portion of the Serra Geral foothills, there is a hydrographic network characterized by high-energy rivers, associated with torrential accumulation consisting of runoff deposits in the distal portions of the foothills. These rivers are characterized by the presence of sandy and gravel bars related to torrential transport processes, dividing the river into several gutters within the floodplain; the location of these gutters are fluctuating over time, as is the case of the Mampituba and Canoas systems. These rivers rest on expressive deposits of alluvial fans reworked by fluvial action, where a braided channel pattern is installed at the foot of the scarp (DANTAS *et al*., 2005).

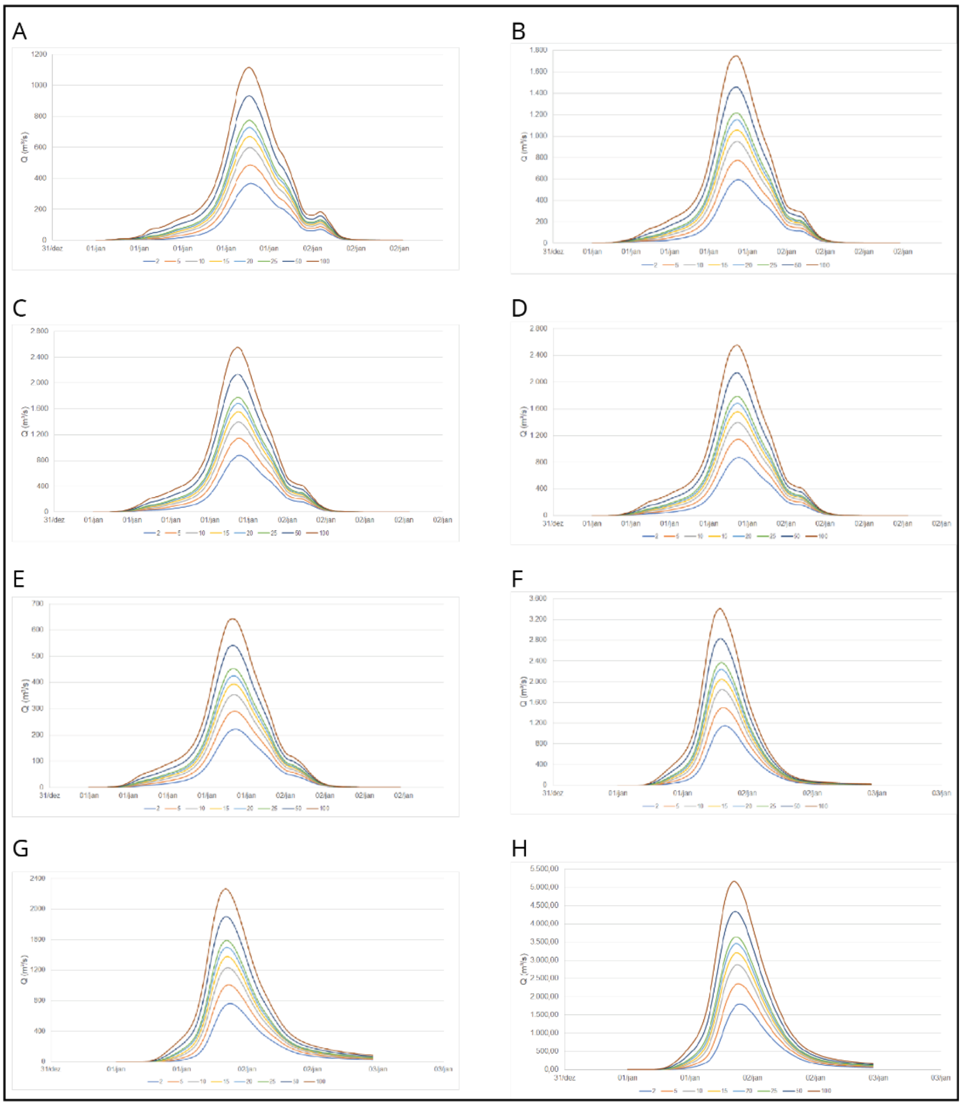
The multitemporal analysis through the evaluation of aerial photographs and orbital images made it possible to identify that the Mampituba River is characterized by its proximity to the Serra Geral foothills, and presents the morphological behavior of a typical intertwined river system, having its channel deeply influenced and altered by episodic high energy flows. Runoff events, with high erosive potential, successively alter the morphology and location of the gutter, creating and abandoning river arms over time. It was observed that the area of the study basin is characterized by alluvial fans, being subject to the occurrence of avulsion phenomena, that is, changes in the direction of the channels. Several erosive streak-like features were visible in the emerged portions, typical of overflows and high-energy water currents which are present in the urbanized regions of Praia Grande and Mampituba.

3.2 Hydrological and hydrodynamic modeling

Dantas (2012) emphasizes that the HEC-HMS model was developed to represent the phases of the hydrological cycle in its aspect of the water balance in the soil. This is constituted by the soil-vegetation interaction, by the transitions of the propagation of groundwater, and the surface runoff in the gutters of rivers and lakes. At point 1 (Figure 5, A), the peak flow calculated with T of 2 years is 364.67 m^3/s, reaching 1,117.5 m^3/s for T of 100 years. At point 4 (Figure 5, D), the flow rate of 872.98 m^3/s was obtained for T of 2 years reaching 2,548.88 m^3/s (T 100 years). When evaluating the sequence of points that follows the Mampituba River (smaller riverbed), there was an average decrease in peak flow of 74.59% from point 4 (872.98 m^3/s - T of 2 years) to point 5 (Figure 5, E) (221.79 m^3/s). When comparing the peak flows at points 5 to 14 (Mampituba River), the flows with a T of 2 years vary from 221.79 m^3/s to 762.11 m^3/s reaching with a T of 100 years 636.93 (Point

5) at 2,266.53 m³/s (Point 14). Points 8 to 13 concern the Canoas/Sertão Rivers. In this region, the peak flows are higher than Mampituba River. At the study basin outlet (Point 15) (Figure 5, H), peak flows range from 1,786.56 m³/s to 5,153.57 m³/s.

Figure 5 – Hydrograph for some points analyzed in the different return periods



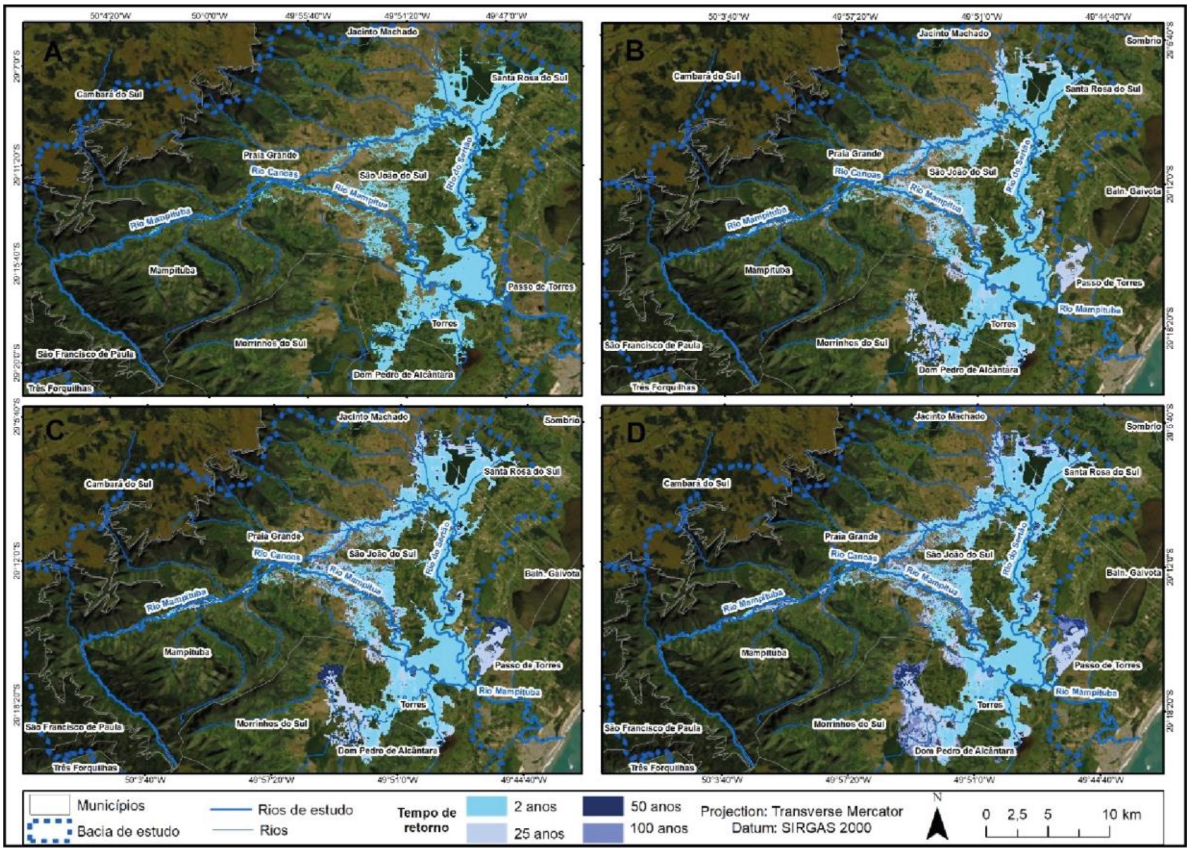
Where: Point 1 (A), Point 2 (B), Point 3 (C), Point 4 (D), Point 5 (E), Point 12 (F), Point 14 (G), and Point 15 (H)
Source: Authors, 2021

An event of heavy rain took place in 2007 in Praia Grande, beginning at 4:00 pm on 03/03/2007 and ending at 3:00 am on 03/04/2007, totaling 211 mm. This event is equivalent to a 15-year T rain (216.6 mm) determined in the hydrological model. The hydrological model built and calibrated for the study basin was integrated with observed, predicted, and simulated data, providing the generation of flows in the sub-basins and stretches used by the hydrodynamic model.

With all sections and other objects created using geoprocessing tools, the set of objects is transformed into HEC-RAS geometry files for import by the model. After loading the geometry, adjustments were made to the river bottoms and the values of Manning's constant. These parameters strongly influence the simulation results and, therefore, the validity of their results.

Figure 6 illustrates the flood patch with T2, T25, T50, and T100 years.

Figure 6 – Flood patch maps for the return periods of T2 years (A), T25 years (B), T50 years (C), and T100 years (D)



Source: Authors, 2021

It can be seen that the area values obtained in the flooding patches for the rivers of interest, in the different return periods, ranged between 8,762.44 ha (T2 years), 10,463.56 ha (T5 years), 11,827.25 ha (T10 years), 12,701.87 ha (T15 years), 13,408.93 ha (T20 years), 13,860.81 ha (T25 years), 14,997.84 ha (T50 years), and 16,755.13 ha (T100 years). It should be noted that the longer the return period, the greater the amount of rain expected and, consequently, the greater the area of the flood spot.

Among the use and occupation of soils in floodable areas, it was observed that the largest floodable area occurs in agricultural areas, followed by field (pasture), and forestry. The topobatimetric survey data carried out at points on the Mampituba, Sertão and Canoas Rivers associated with the available MDE were satisfactory to minimize modeling uncertainties.

According to Brown and Pasternack (2014), the increase in flows in mountainous regions associated with the transport of sediments causes changes in the course of rivers. This situation is found in the area of the study basin of this research. Szymanski (2020) performed a hydrodynamic modeling in the Molha Coco and the Malacara River basin in Praia Grande City, southern Santa Catarina State, which identified that 70% of the flooded points represented by the hydrodynamic model using the HEC-RAS coincided with the collected points in the field in an event of intense rainfall in 2007. This condition corroborates the results obtained with the flood spots in the simulated return periods in the study basin area.

4 FINAL CONSIDERATIONS

The study evaluated the flooding patches in an area of the Mampituba, Canoas, and Sertão River basins, characteristic of mountainous regions in southern Brazil. The HEC-RAS model was used to simulate flood events in this study area based on hydrological data from historical records and field surveys. The main points observed were:

1 The HEC-HMS hydrological model allowed the generation of hydrographs with peak flows at different return periods.

2 The 216.6mm rainfall for a 15-year TR generated in the hydrological model is equivalent to the intense rain event (211mm) recorded in March 2007 in Praia Grande, which shows that the results of the hydrological modeling can be considered satisfactory.

3 Spot maps show that floods occur within river channels and at spillage sites. These regions are mainly occupied by agriculture, fields, and forestry, followed by residences, inns, and restaurants, which can suffer structural damage which could be life-threatening to people living in these areas.

4 The creation of an MDT for the Rio Grande do Sul State with better spatial resolution was possible. In the Santa Catarina State, the MDT (SIGSC) has a special resolution of 1m, while in the Rio Grande do Sul State, the SRTM (Shuttle Radar Topoghaphy Mission) has a spatial resolution of 90 meters.

5 In this study, data from three automatic stations in the study basin were used, being 2 fluviometric stations and 1 pluviometric station. The implementation of a pluviometric and pluviometric monitoring system along the 15 points evaluated by the hydrological modeling would contribute to the execution of a hydrological and hydrodynamic modeling with more base information.

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REFERENCES

Associação Brasileira de Normas Técnicas (ABNT). 1994. **NBR 13.133 - Execução de Levantamento Topográfico**. ABNT, 35 p.

APEL, H.; THIEKEN, A. H.; MERZ, B.; BLÖSCHL, G. 2006. A Probabilistic Modelling System for Assessing Flood Risks. **Natural Hazards**, v. 38, n. 1-2, p. 79-100.

ARDUINO, G.; REGGIANI, P.; TODINI, E.; 2005. Recent advances in flood forecasting and flood risk assessment**. Hydrology & Earth System Sciences**, v. 9, n. 4, p. 280-284.

BATISTA, M.; LARA, M. 2012. **Fundamentos de engenharia hidráulica**. Belo Horizonte. Editora: UFMG. 473 p.

BACK, Á. J.; POLETO, C. Distribuição espacial e temporal da erosividade das chuvas no estado de Santa Catarina, Brasil. **Revista Brasileira de Climatologia**, v. 22, n. 14, p. 1-23, jan. 2018.

BACK, Á. J. Informações climáticas e hidrológicas dos municípios catarinenses (com programa HidroClimaSC). Florianópolis: Epagri, 2020. 157p.

BOITEN, W. 2008. **Hydrometry: IHE Delft lecture note series**. CRC Press. 3ª edição.

BHUIYAN, M. J. A. N.; DUTTA, D. 2012. Analysis of flood vulnerability and assessment of the impacts in coastal zones of Bangladesh due to potential sea-level rise. **Natural Hazards**, v. 61, n. 2, 729-743.

BRASIL. 2003. **Plano de manejo: Parque Nacional de Aparados da Serra e Serra Geral**. Encarte 3. Brasilia: Ministério Do Meio Ambiente-Ibama.

BROWN, R. A.; PASTERNACK, G. B.2014 Hydrologic and topographic variability modulate channel change in mountain rivers. **Journal of Hydrology**, v. 510, p. 551-564.

CABRAL, S. L.; CAMPOS, J. N. B.; SILVEIRA, C. S.; TEIXEIRA, F. A. A. 2016. Integração do SIG HEC/HMS e HRC/RAS no mapeamento de área de inundação urbana: aplicação à bacia do rio Grangeiro-CE. **Geociências**. São Paulo, v. 35, p. 90-101.

CHOW, V.T. 1959. Open Channel Hydraulics. McGraw-Hill, New York.

COLLISCHONN, Walter; DORNELLES, Fernando. 2013. **Hidrologia para engenharia e ciências ambientais**. Porto Alegre: Associação Brasileira de Recursos Hídricos. 342p.

DANTAS, M. E.; GOULART, D. R.; JACQUES, P. D.; ALMEIDA, I. S.; KREBS, A. S. J. 2005. **Geomorfologia aplicada à gestão integrada de bacias de drenagem: bacia do rio Araranguá (SC), zona carbonífera sul-catarinense**. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 16.,. 2005, João Pessoa, PB., Anais... João Pessoa, PB: ABRH, 74p. CD Rom.

DANTAS, C. E. O. 2012. **Previsão e Controle de Inundações em Meio Urbano com Suporte de Informações Espaciais de Alta Resolução**. 2012. 221p. Tese (Doutorado em Engenharia Civil), Universidade Federal de Pernambuco.

DUTTA, D.; HERATH, S.; Musiake, K. 2006. An application of a flood risk analysis system for impact analysis of a flood control plan in a river basin. **Hydrological Processes**, v. 20, n. 6, p. 1365-1384.

DUTTA, D.; TENG, J.; VAZE, J.; LERAT, J.; HUGHES, J.; MARVANEK, S. 2013. Storage-based approaches to build floodplain inundation modelling capability in river system models for water resources planning and accounting. **Journal of Hydrology**, v. 504, p. 12-28.

FAN, F. M.; COLLISCHONN, W. 2014. Integração do modelo MGB-IPH com sistema de informação geográfica. **Revista Brasileira de Recursos Hídricos**. v. 19, n. 1, p. 243-254.

FAN, F. M.; SCHWANENBERG, D.; COLLISCHONN, W.; WEERTS, A.; 2015. Verification of inflow into hydropower reservoirs using ensemble forecasts of the TIGGE database for large scale basins in Brazil. **Journal of Hydrology: Regional Studies**, 4, 196-227.

GALLEGOS, H. A.; SCHUBERT, J. E.; SANDERS, B. F. 2009. Two-dimensional, high-resolution modeling of urban dam-break flooding: A case study of Baldwin Hills, California. **Advances in Water Resources**, v. 32, n. 8, p. 1323-1335.

HUFF, F. A. Time Distribution of Heavy Rainstorms in Illinois. Illinois State Water Survey, Circular 173, p. 19. Jang, S.H.,1990.

Instituto Nacional de Colonização e Reforma Agrária (INCRA). 2013. **Manual técnico de posicionamento e georreferenciamento de imóveis rurais**. Brasília. 1ª ed.

KNEBL, M. R.; YANG, Z. L.; HUTCHISON, K.; MAIDMENT, D. R. 2005. Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event. **Journal of Environmental Management**, v. 75, n. 4, p. 325-336.

KARIM, F.; DUTTA, D.; MARVANEK, S.; PETHERAM, C.; TICEHURST, C.; LERAT, J.; KIM, A.; YANG, A. 2015. Assessing the impacts of climate change and dams on floodplain inundation and wetland connectivity in the wet–dry tropics of northern Australia. **Journal of Hydrology**, 522, 80-94.

LASTRA, J.; FERNÁNDEZ, E.; DÍEZ-HERRERO, A.; MARQUÍNEZ, J. 2008. Flood hazard delineation combining geomorphological and hydrological methods: an example in the Northern Iberian Peninsula. **Natural Hazards**, v. 45, n. 2, p. 277-293.

MARINHO FILHO, G. M.; ANDRADE, R. S.; ZUKOWSKI JUNIOR, J. C.; MAGALHÃES FILHO, L. N. L. 2013. Modelos hidrológicos: conceitos e aplicações. **Revista de Ciências Ambientais**, v. 6, n. 2, p. 35-47.

MERZ, B.; KREIBICH, H.; SCHWARZE, R.; THIEKEN, A. 2010. Review article 'Assessment of economic flood damage'. **Natural Hazards Earth Syst Sciencies**, v. 10, n. 8, p. 1697-1724.

NETO, A. R.; CIRILO, J. A.; DANTAS, C. E. O.; Silva, E. R. 2015. Caracterização da formação de cheias na bacia do rio Una em Pernambuco: simulação hidrológica-hidrodinâmica. **Revista Brasileira de Recursos Hídricos**. v. 20, n. 2 p. 394-403.

RIBEIRO, C. B. M.; LIMA, R. N. S. 2011. Simulação de inundações urbanas a partir da integração de técnicas de geoprocessamento à modelagem hidráulica e hidrológica. **Revista de Geografia**. v. 2, n.1, p.1-9.

SARTORI, R. Z. 2018. **Avaliação comparativa de modelos hidrodinâmicos para previsão de inundações: um estudo de caso do município de Getúlio Vargas-RS**. 2018. 147p. Dissertação (Mestrado em Ciência e Tecnologia Ambiental). Universidade Federal da Fronteira Sul. Rio Grande do Sul.

SECRETARIA DO MEIO AMBIENTE do Rio Grande do Sul. 2020. **Diagnóstico do Plano de Recursos Hídricos da Bacia Hidrográfica do Rio Mampituba. Fase A - Diagnóstico**. 219p.

SILVA, E. R. 2015. **Modelagem integrada para controle de cheias, previsão e alerta de inundações: estudo de caso da bacia do rio una em Pernambuco**. 2015. 145f. Tese (Doutorado em Ciências em Engenharia Civil). Universidade Federal de Pernambuco. Pernambuco.

SILVEIRA, A.L.L. 2005. **Desempenho de fórmulas de tempo de concentração em bacias urbanas e rurais.** In: Revista Brasileira de Recursos Hídricos, v.10, n.1, Jan/Mar 2005, 05-24.

SZYMANSKI, F. D. **Análise de inundações em bacias montanhosas no sul do Brasil por meio de monitoramento e modelagem**. 2020. 123p. Dissertação (Mestrado em Energia e Sustentabilidade). Universidade Federal de Santa Catarina.

TENG, J.; JAKEMAN, A. J.; VAZE, J.; CROKE, B. F. W.; DUTTA, D.; KIM, S. 2017. Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. **Environmental Modelling & Software**, v. 90, p. 201-216.

TUCCI, C. E. M. 1998. **Modelos hidrológicos**, Ed. Universidade /UFRGS/ Associação Brasileira de Recursos Hídricos, Porto Alegre. 668p.

USACE-HEC. 2016a. **Hydrologic Modeling System, HEC-HMS v4.2.1 - User's Manual**. US Army Corps of Engineers, Hydrologic Engineering Center. 614p.

USACE-RAS. 2016b. **River Analysis System, HEC-RAS v5.0 - User's Manual**. US Army Corps of Engineers, Hydrologic Engineering Center. 960p.

USACE-RAS. 2016bc. **River Analysis System, HEC-RAS v5.0 - 2D Modeling User's Manual**. US Army Corps of Engineers, Hydrologic Engineering Center. 171 p.

VAZE, J.; VINEY, N.; STENSON, M.; RENZULLO, L.; VAN DIJK, A.; DUTTA, D.; CROSBIE, R.; LERAT, J.; PENTON, D.; VLEESHOUWER, J.; PEETERS, L.; TENG, J.; KIM, S.; HUGHES, J.; DAWES, W.; ZHANG, Y.; LEIGHTON, B.; PERRAUD, J.-M.; JOEHNK, K.; YANG, A.; WANG, B.; FROST, A.; ELMAHDI, A.; SMITH, A.; DAAMEN, C. 2013. The Australian Water Resource Assessment System (AWRA). **20th International Congress on Modelling and Simulation**. Adelaide, Australia. p. 3015-3021.

VIOLA, M. R.; MELLO, C. R.; ACERBI JR., F. W.; SILVA, A. M.; 2009. Modelagem hidrológica na bacia hidrográfica do Rio Aiuruoca, MG. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.13, n.5, p.581-590.

WEBER, E.; HASENACK, H.; FERREIRA, C. J. S. 2004. **Adaptação do modelo digital de elevação do SRTM para o sistema de referência oficial brasileiro e recorte por unidade da federação**. Porto Alegre, UFRGS, Centro de Ecologia.

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